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RESEARCH REPORT
Concepts

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PRIMARY STUDENT TEACHERS' UNDERSTANDING OF THE PARTICULATE NATURE OF MATTER AND ITS TRANSFORMATIONS DURING DISSOLVING

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ABSTRACT: One-to-one interviews were administered to a sample of twenty female primary student teachers (PST), who were studying at the University of Cyprus. They were asked to describe the changes in macroscopic (colour, taste, volume, density, flammability) and microscopic (kind and movement of molecules) properties of substances when dissolving salt or sugar in water, when mixing water and alcohol, or when filtering or heating the respective water solutions. Analysis of the transcribed interviews showed that the majority of the PST exhibited perceptual rather than conceptual understanding of the particulate nature of matter and had difficulties to relate the observable macroscopic changes to the invisible molecular events (arrangement and movement of molecules). They stated instead that molecules share in observable properties of matter and combine together to give new molecules, without realising the changes in the structure and the properties of matter or without being able to distinguish physical from chemical changes. The prevalence and the diversity of the observed conceptions among PST indicate that the molecular constitution of matter is not adequately understood and that teaching materials and instructional interventions based on conceptual change should be designed and implemented both for teachers' pre-service and in-service training, to avoid 'diffusion' of misconceptions within the primary classrooms. [*Chem. Educ. Res. Pract. Eur.*: 2000, *1*, 249-262]

KEY WORDS: *dissolving; particulate nature of matter; alternative frameworks; student conceptions; transformations of matter*

INTRODUCTION

Science educators would agree that appropriate understanding of the particulate nature of matter is essential to the learning of chemistry concepts (Anderson, 1986; Duncan & Johnstone, 1979; Hackling & Garnett 1986) as well as the learning of states of matter and the changes associated with heating or cooling a substance, such as, thermal expansion or changes of state (Osborne & Cosgrove, 1983; Bar, 1989). This understanding is also essential to grasping the nature and importance of everyday phenomena such as the process of dissolution of substances. Lee, Eichinger, Anderson, Berkheimer, and Blakeslee (1993) identified several misconceptions held by middle school students relating to the process of dissolving. At the macroscopic level, students talked about dissolving in ways that did not distinguish it from disappearance or melting. They thought that "sugar dissolves into nothing" or that it "eventually becomes water or changes into liquid sugar". Prior to or even after instruction, they were also unable to give molecular explanations of dissolving. Many thought that sugar would sink to the bottom of the water in a cup and stay there because it is a solid or because sugar molecules are heavier.

Earlier studies (Osborne & Cosgrove, 1983; Longden, Black, & Solomon, 1991) had investigated students' conceptions on dissolving, but they focused primarily on the idea of conservation of matter during dissolving. The process of dissolution also attracted the attention of some other studies. These investigations focused on quantitative aspects of solution, such as solubility (Gennaro, 1981) or concentration (Gabel & Samuel, 1986), on how external factors, such as, stirring and change in temperature affect the process of dissolution of a solid in a liquid (Blanco & Prieto, 1997), on whether students' conceptions relate to their everyday experiences or the science instruction (Prieto, Blanco, & Rodriguez, 1989), and the identification of students' physical and logico-mathematical knowledge of sugar solutions or the relationship of these two types of knowledge (Slone & Bokhurst, 1992).

Other studies conducted in different contexts (Atwood & Atwood, 1996; Bendall, Goldberg, & Galili, 1993; Haidar, 1997) concluded that teachers exhibit a wide range of misconceptions similar to those of their students. Carlsen (1993) also identified a relationship between teacher subject-matter knowledge and either the cognitive level of their questions or teacher domination of the teaching floor. When the teachers were less topic knowledgeable, they were more likely to rely upon low-level questions and to give their students less opportunities to speak. Misconceptions arise, however, not only from students' contacts with the physical and social world (Strauss, 1981) and from textbooks (Cho, Kahle, & Nordland, 1985), but also as a result of interaction with teachers (Gilbert & Zylberstajn, 1985).

The scarcity of research related to teachers' misconceptions in science is probably "a way of avoiding the suggestions that teachers have misconceptions or an exceptionally subtle way of developing teacher's science-conceptions" (Goodwin, 1995, p. 108). Teachers' knowledge of the subject matter and their conceptions about the phenomena they teach can enhance or limit students' learning. Constructivist approaches to teaching and learning also acknowledge the role that prior conceptions held by learners play in the learning process. Science educators should accordingly devote research efforts to elicit and build on prospective teachers' conceptions if they want to accommodate for these conceptions during pre-service or in-science training.

The present study focused upon primary student teachers' (PST) conceptions relating to aspects of dissolving a solid (sugar or salt) or a liquid (alcohol) in water and the effects of filtering or heating the respective solutions. The extent of PST's understanding of both the macroscopic (taste, colour, volume, or flammability) and microscopic (kind and movement of molecules) properties and changes during the dissolution process as well as when filtering or heating the respective solutions was investigated using one-to-one clinical interviews. The collected information provides grounds for judging whether PST's ideas relate to everyday experiences or to science instruction received at the primary and the secondary level of education. This information is very useful for the designing and implementation of instructional interventions conducive to conceptual change among PST, who may act as catalysts for conceptual change instructional approaches at the primary level of education.

PROCEDURE

One-to-one interviews were administered to a sample of twenty female primary student teachers (PST) of different backgrounds in science. The subjects were students at the *Education Department* of the *University of Cyprus* who enrolled in a compulsory science course for PST. The subjects did not have any science courses at the university level. Students were informed that the information from the interviews was to be used for the designing of the course and they volunteered to be interviewed. Each interview session, which lasted about 30 minutes, was tape-recorded and transcribed for further analysis.

The interview consisted of two major categories of questions. In the first category, students were asked to describe macroscopic (colour, taste, volume, density, flammability) properties of solids and liquids and how these properties change when dissolving a solid (salt or sugar) in a liquid (water) or when mixing two liquids (water and alcohol). Students' conceptions of the effects of filtering or heating the water solutions were also examined. The second category of questions asked the subjects to relate the macroscopic changes to the particulate nature of matter (kind and movement of molecules). Each student was first asked to predict the macro- and micro-changes which would occur during the process of dissolution or when filtering or heating the respective solutions. The water solutions (salt, sugar, and alcoholic solution) were subsequently prepared in front of each student. Some other simple demonstrations, followed by a series of questions designed to probe their understandings of the demonstrated phenomena, were also used.

RESULTS AND DISCUSSION

Dissolving sugar or salt in water

Students were initially asked to predict what would happen if one or more spoonfuls of salt or sugar were added in a glass vessel containing tap water and to compare the mass (weight), the volume, and the density of tap water prior and after dissolving sugar and salt in it. Table 1 shows PST's predictions and their explanations regarding the dissolution of salt or sugar in tap water.

Some students thought that salt (6 students) or sugar (8 students) would sink to the bottom and stay there, because "it was heavier" than water. When a spoonful of solid (sugar or salt) was added in water, students observed its grains to the bottom and 3 more students changed their minds explaining that they were wrong when they stated that sugar would not be seen in water because of dissolving (2 students) or melting (1 student). The rest of them believed that the observed phenomenon consisted of partial melting or dissolution of the solid material with a residue at the bottom.

When, after stirring, they observed that the solid "was not there any more", they proposed that the solid "melted" or dissolved. The students, who initially proposed that the solid would sink in the bottom, insisted that the solid dissolved as a consequence of stirring and that without stirring the solid would not dissolve, no matter how long we waited (e.g., till next day). Four of them expected that when we stopped stirring the liquid, the solid grains would reappear at the

TABLE 1. *Frequencies of prospective primary school teachers' conceptions regarding the dissolution of sugar and salt in water, and the filtering of the respective solutions (n = 20).*

	Predictions		After adding the solid		After stirring the solution	
Conceptions	Salt	Sugar	Salt	Sugar	Salt	Sugar
Solid sinks	6	8	9	11	4	4
Solid melts	6	9	5	8	8	11
Solid dissolves	8	3	6	1	8	5
No explanation					3	1
Grains break up into smaller grains						
Smaller grains of different size					3	3
Smaller grains of equal size					1	
Correct explanation					1	1
Volume equals to the sum of the volumes	20	20				
Conservation of mass	20	20				
Density						
Intermediate between that of solid and of liquid	12	12				
Increasing from top to bottom	8	8				
Taste						
Sweet		20				
Salty	20					
Type of change						
Physical change	8	7				
Chemical change	5	8				
Do not know	7	5				
Filtering of solutions						
It remains on the filtering paper	7	13				
Part of it remains on the filtering paper	3	3				
It does not remain on the filtering paper	10	4				

bottom of the container. The dissolution was thus conceived as a momentary and reversible phenomenon. This idea appeared to be prevalent and persistent among students ranging in age from 12 to 18 years old (Blanco & Prieto, 1997), and it seems to be related to everyday experiences regarding solutions where there is residue at the bottom of the container.

Some other students expressed from the beginning the idea that salt (8 students) or sugar (3 students) would dissolve in water, or that salt (6 students) or sugar (9 students) would melt. Among those who proposed that salt would dissolve in water, two could not provide any explanation. The rest of them suggested that solid grains (sugar or salt) break up into "smaller and invisible grains" which are called atoms or molecules and exist in solid state in the solution.

Two of them did not conceive the "smaller and invisible grains" as primary building blocks of matter that pre-exist. They consider them as the final link in a process of division (Pfundt, 1981) because continuous matter can, under certain conditions, be divided up into small particles which retain the properties of matter, while their size depends on the conditions during the division. Only one student gave an almost correct explanation of the dissolution process, that is, she proposed that the molecules of the solid material would be dissociated and form a homogeneous solution where the solvent and the solute would be indistinguishable, but she did not seem to recognise the importance of solute-solvent interaction. The solvent was regarded in all cases as a rather passive component, which was absorbed by the solid grains causing thus their dissolution. The majority of students insisted, however, that after dissolving or melting the molecules would exist in liquid form.

Some of these students believed that during the process of dissolution an entirely different substance is formed, that is, a chemical reaction changed the original molecules into a new substance, "salty water" or "sugary water". 5 and 8 students exhibited the reaction model when salt or sugar was added in water, respectively. Nevertheless, from their own perspective, the sweetness or the salinity of the solution would remain unaffected and, furthermore, "if the solution is filtered, sugar (or salt) will remain on the filter paper". Many students supported the notion that filtering is a process for separating salt (7 students) or sugar (13 students) from the respective solutions. Three more students thought filtering could be used for separating the solid from the liquid solution depending on the size of the "smaller and invisible grains". The size of these grains depended on the process of stirring and would not necessarily be equal for all grains. Thus, the bigger ones would remain on the filter paper and the filterable liquid would be less sweet (or salty).

These ideas are incompatible with dissolving as a physical change, and, more importantly, with dissolving as a chemical change which transforms the original substances into totally new substance(s). The perceptual experience of using filtering to separate undissolved solids from a liquid dominated students' thought and filtering was imagined as a general method of separating solids from water solutions (or other liquid solutions) irrespectively of their solubility or the chemical changes that may occur. From the students' perspective chemical change was a process of combining or adding together molecules of different kinds without actually affecting their basic properties. The formation of new molecules was conceived as the result of adding together or mixing the initial molecules rather than a new particle with different properties than those possessed by the initial molecules with the initial molecules no longer present (Anderson, 1990; Meheut, Saltiel, & Tiberghien, 1985). The following excerpts from PST's *answers* (A) to questions (Q) raised during the interviews exemplify students' thinking.

Q. -When you say, "it melted", what do you mean? A. -*It means that it became liquid*. Q.- Can you propose an example for this change? A.- *Yes. When we heat ice it melts*. Q. - What does it mean? A. - *It means that the solid becomes liquid*. Q. - What must we do to change solid sugar to liquid sugar? A. - *We must put it in water or any other liquid*. (after adding a spoonful of solid in the cylinder containing water, the solid sank in the bottom) Q.- You see now that the solid is there. A. - *Yes, but we have to stir it first*. Q. - Let's do it. (sugar dissolved) A. - *You see now. Sugar cannot be seen. It melted, and when it melts it changes into liquid*. Q. - Probably there is no sugar any more in the cylinder. A.- *No, it is there. We can't see it because it changed to liquid... We have two liquids now. We do not see the liquid sugar because water is liquid as well*. Q. - How do we know it? A. - (laughing). *We can drink some water. We shall realise then that sugar is there because the water will be sweet*. Q. - Is there any other way to identify the existence of sugar in the water? A. (after some hesitation) *Yes, in case we filter the solution, then sugar (or salt) grains will remain on the filter paper*. Q. - You mentioned earlier that sugar turned into liquid. How is it possible to filter the mixture and obtain solid sugar on the filter paper? A. - *Liquid sugar will stay on the filter paper .... No , no we will obtain solid sugar, but I do not really know why*.

Q. -Is dissolving a solid in water a physical or a chemical change? A. - *It's a chemical change*. Q. - What happens to sugar, where is it now? A. - *It is in the water. Its molecules combined with water molecules and we have a new substance, we have ... sugary water*. Q. - Is there any way to separate sugar from water? A. - *Yes, we can filter the liquid*. Q. But, you told me earlier that a new substance has been created, how can we take back the solid again? A. *Sugar molecules were initially combined with water molecules and when we filter .....I can't really explain it, but I am sure that sugar (or salt) will remain on the filter paper*.

Questions concerning saturated and unsaturated solutions were not used and there was a deliberate attempt to avoid dissolving near or beyond the point of saturation. All the students conserve the amount of matter and used perceptual evidence showing that sugar was in the container after dissolving because of the taste of the solution. They also insisted that the volume of the solution would increase as much as the volume of the added salt or sugar and that the density would increase as well, because "salt (and sugar) is more dense than tap water". The increase in density was thus conceived as being intermediate between the density of water and the density of the respective solid. There were not, however, indications that students realise the existence of empty space inside the matter beyond the repetitions of declarative statements concerning the molecular constitution of matter.

Eight students did not conceive the solution as homogenous and they thought that the density of the solution decreases as the distance from the bottom of the container increases, that is, the solution would be less dense as we move from the bottom to the top because the heavier molecules of the solid tended to sink. Four of them were among the students who initially thought that the solid (sugar or salt) will sink to the bottom and stay there even after stirring the mixture. The perceptual evidence after the addition of the solid (sugar or liquid) in water and the stirring procedure induced them to believe that "sugar and salt molecules being heavier than water molecules have a tendency to sink". A force "similar to upthrust" was preventing them from sinking to the bottom and keeping them in equilibrium. These students conceived the molecules as being in the solid state and having the macro-properties of the initial solids. They exhibited also the conception that molecules of solids do not move.

In those instances where students expressed particulate ideas concerning the process of dissolving, their consequent explanations were not consistent with the particulate theory of matter. Students, for example, who supported that solid (salt or sugar) would dissolve in water, believed that molecules would be in liquid form or in solid form, but they would not move at all. These students seemed familiar with molecular language and ideas but they did not exhibit adequate understanding of dissolving as a process where molecules of a liquid hit the grains of the solid which break away and spread evenly in the liquid, while they continue to be in never ending motion and interaction in empty space. Not any subject made reference to the difference between sugar and salt solution, that is, the first being molecular and the second ionic solution and this difference was deliberately ignored.

TABLE 2 *Frequencies of prospective primary school teachers' conceptions regarding the dissolution of alcohol in water (n = 20).*

Conceptions	Before mixing the liquids	After mixing the liquids
Two layers will be formed		
The liquid added second on top	2	1
The less dense on top	7	3
Three layers will be formed	3	0
The liquids will be mixed up	8	16
Type of change		
Physical change	7	0
Chemical change	8	17
Do not know	5	3
Alcohol loses its flammability	20	20
Conservation of volume	20	0
Some drops remain in the other cylinder		5
Vapours escaped from the liquids		6
Do not know		9
Alcohol molecules are bigger than water molecules	12	12
Molecules move	20	20
Conservation of mass	20	15

Dissolving alcohol in water

The process of preparing the alcoholic solution was somewhat different in an attempt to further investigate the existence of empty space between molecules. Tap water was poured in a volumetric cylinder so that its volume (i.e., 100 cm^3) was measured. Similarly, alcohol (i.e., 80 cm^3) was poured in a second volumetric cylinder. Students were asked to predict what would happen when the two liquids were added together in one of the cylinders and to compare the mass (weight), the volume, and the density of the "added together" liquids. Table 2 presents the main conceptions expressed by the subjects of the study before and after mixing the two liquids.

Nine students insisted that one of the liquids will float upon the other so that layers of the two liquids will be distinguished in the cylinder. Two insisted that the floating liquid would be the one added second and the rest that the less dense liquid will float upon the denser one. Three students expressed the idea that there would be three layers although we would be unable to distinguish them. The layer at the bottom consisting of the more dense liquid, the intermediate layer consisting of a solution of the two liquids, and the layer at the top consisting of the less dense liquid. Only five students believed that the two liquids would form a homogenous mixture. When the two liquids were added together in the same cylinder, four students insisted that "there are layers of the two liquids, but we cannot distinguish them because both liquids are colourless and transparent."

Eight of the students also believed that a chemical change would occur forming a new substance, but all of them, without any reservation, insisted that the volume of the "added together" liquids would be exactly the sum of the volumes of the two initial liquids. When the two liquids were mixed up in their presence, they were challenged to think about alcoholic beverages and to explain the mixing of water and alcohol as well as the reduction in volume. Nine more students changed their minds after the mixing of the liquids and proposed that the reduction in volume indicated a chemical change. All students believed, however, that alcohol would lose its flammability after mixing up the two liquids without it being necessary to have a chemical transformation. Even those who insisted earlier, that despite the chemical change, sugar and salt solution would preserve its relative sweetness or salinity, insisted that alcohol would lose its flammability after mixing with water.

A bank note, after being immersed in the alcoholic solution, was approached to a lit match. The students observed the flames around the bank note and they expressed their anxiety for burning it. The flames went out and the bank note did not burn and remained furthermore wet. Students were then challenged to give an explanation to the demonstrated phenomenon. None of the students provided an adequate explanation, but when they were subsequently asked whether the alcoholic solution is flammable 15 students gave a positive answer. Eight of them were among those who supported earlier that there would be a chemical change when mixing water and alcohol.

Students provided different reasons to explain the reduction in volume supporting their initial conceptions. Five students proposed that "some drops of the liquid remain in the other cylinder". Six more students insisted that "the volume is less because water and alcohol vapours escaped" and the rest nine students could not provide any explanation. The reduction in volume induced five students to believe that "we do not have conservation of volume and that mass would not be conserved as well. I was wrong, when I insisted earlier that the total mass of the solution would equal the sum of the masses of the two liquids." From the students' perspective, this was a really discrepant event, which caused a regression in their conservation reasoning. Piaget and Inhelder (1974) found that the conservation of mass (for transformations involving balls of clay and dissolving of solid in water) is related to the reversibility of these transformations. The reversibility of the process is not so obvious in the case of dissolving alcohol in water and, consequently, conservation reasoning becomes more difficult. The application of the law of conservation of matter to chemical changes is, furthermore, a far more complex and difficult process (Hesse & Anderson, 1992). Conservation of mass should be explained in terms of microscopic changes and the conservation of atoms in order to facilitate conservation reasoning for transformations of matter where the reversibility of the process is not so obvious from the learners' perspective.

Twelve of the subjects conceived water molecules to be bigger than alcohol molecules and all the subjects stated that molecules move by vibrating around their position. Even those who insisted earlier that the tiny grains of salt (or sugar) do not move, believed that "molecules of liquids always move. This is why we used containers to keep them from flowing away". The

TABLE 3. *Frequencies of prospective primary school teachers' conceptions regarding the effects of heating the water solutions (n = 20).*

Conceptions	Frequencies of conceptions
Effect s of heating	
Liquids expand	10
Molecules expand	5
Molecules do not expand	5
Some liquids expand	2
Liquids do not expand	8
Evaporation of water	
Vapour molecules the same as water molecules	5
Chemical change	
Water changes to air	6
Gases of O_2 and H_2 are formed	7
Do not know	2
Evaporation of solutions	
Solid remains to the bottom	
Salt	16
Sugar	12
Partial evaporation of solid	
Salt	2
Sugar	3
Solid evaporates too	
Salt	2
Sugar	5
Boiling and evaporation are not differentiated	20
Fractional differentiation totally unknown	20

movement of molecules of liquids was thus related to the property of fluidity (liquidity) rather than to the particulate nature of matter and its kinetic theory.

Heating the water solution

Some of the students' conceptions related to the effects of heating the respective water solutions are presented in Table 3.

When the students were asked to predict what would happen in case we heated the solutions in each container, all the students believed that the temperature would increase and that this would be the only change that would happen. These students did not believe that liquids expand when heated. The other half of the students believed that liquids expand when heated, but only five of them explained thermal expansion as the result of the molecules moving faster and bouncing further apart. Only these students connected the increase in temperature to the movement of molecules, but none of the students was quite familiar with the idea of temperature as a measure (or a consequence) of the mean kinetic energy of the particles of the liquid. Seven students attributed the expansion of the liquid to the expansion of the molecules themselves.

It was, however, unanimously believed that the liquid will start "evaporating" at a certain temperature, but the temperature will necessarily continue to rise unless we stop heating. Students did not know that the boiling point is a constant temperature, characteristic of a liquid and that this temperature is related to its volatility. When they were informed that the boiling point is necessarily a constant temperature, they insisted that "...this is impossible because we continue to heat the water solution and, thus, the temperature will continue to rise." The concept of fractional distillation was totally unfamiliar to the students who did not recognise that the two liquids in a liquid mixture (i.e., mixture of water and alcohol or wine) are not equally volatile. When the boiling points of the water and alcohol were given (100 ^{o}C, 80 ^{o}C), only two of them could provide adequate explanation why the two liquids could be separated by means of distillation making use of the difference in boiling point. These students attempted also to explain the demonstrated phenomenon with the bank note. Their correct explanations made reference to the dissolution of alcohol in water as being a physical change, to the lower boiling point of alcohol, its greater volatility in comparison with water, and the flammability of its vapours. They wanted also to go back and change their explanations about the dissolution of sugar and salt. The simple demonstrations during the interview proved to be successful teaching interventions leading to conceptual change.

All the students were also unable to differentiate boiling and evaporation and they could not conceptualise the transformations of energy during boiling, or evaporation in general. They could not connect the escaping of molecules from a liquid during boiling to the conversion of a proportion of their kinetic energy (the escaping molecules must have much higher kinetic energy than the average for these in the liquid) into potential energy and, consequently, they were unable to conceptualise the latent heat of evaporation.

The vapours (the steam)

Five students realised that when a liquid evaporates, only the form of the liquid changes, but not its mass or basic nature. These students proposed that vapours consist of the same molecules as the molecules of water in the water solution or the molecules of the new substance, when they believed a chemical change had occurred, or the molecules of the components in the water solution, when they believed that solid sugar or salt and other substances evaporate as well. They understood that the molecules change motion and arrangement and do not change their basic nature, and that during evaporation only the outward appearance of a liquid changes. The rest of the students believed that the molecules of the vapour should be different from the molecules of water or the molecules in the water solution. Two of them could not give any explanation for this difference. Six students proposed that water changes to air when it boils, air and vapours being conceived as identical. Air molecules were considered to be of just one kind. This was an indication of their inability to understand air as a mixture of different gases (or vapours).

Seven students suggested that evaporation is a chemical change where gases of oxygen and hydrogen are produced. Most of the students proposed that molecules speed up on heating and they tend to move apart, while some students indicated that the size of molecules depends on their temperature (10 students) or that vapours consist of even bigger molecules (4 students) because "... they continue to expand. As we all know material bodies expand when heated."

All the students understood that in a gas (vapours) the molecules are further apart than those in solids and liquids and move with high velocities, colliding with one another and with the wall of the vessels containing them. This idea was an indication that students understood the existence of empty space in matter, at least in the gaseous state. Molecules' motion was described as resembling Brownian motion, that is, they move randomly and irregularly in every direction, but they tend always to go up because gases (and vapours) are lighter and tend to rise. Seventeen students believed that collisions were not the causes of the change in the direction of movement and were not considered necessary for such a change. These students tended to refer to vapour molecules as having volition similar to human beings, as it is indicated by the following excerpt from a dialogue with one of them

Q. How do the molecules of vapours move? A. *They go up.* Q. So, all of them move upwards. A. *Yes... No, I think that they change direction of movement and move in every direction, but nevertheless they finally go up*. Q. Why do they change direction and how do you think this change happens? A. *This is the way they move, because of their nature*. Q. Do they change direction, let's say, only after a collision occurs? A. *No, I do not think that this is necessary. We learnt in science that the molecules move randomly and irregularly in every direction and that they change the direction of their movement very often.* (The student sketches a movement resembling the Brownian motion as it is depicted in many textbooks.)

Concerning the effects of heating on the soluted salt or sugar, students believed that salt (16 students) and sugar (12 students) will finally remain at the bottom of the container. Some students thought that the water vapours would contain some vapours of salt (2 students) or sugar (3 students) and that the solid at the bottom of the container would thus be less. The rest of the students believed that all the quantity of salt (2 students) or sugar (5 students) would be somehow transformed into vapours. These ideas confirm what has been discussed earlier about the reaction model exhibited by the students or their ideas about dissolving as being synonymous to liquefaction.

CONCLUSIONS AND IMPLICATIONS

Evidence from the interviews showed that many primary student teachers (PST) faced difficulties in understanding macroscopic and microscopic properties of matter and the changes which take place during the dissolution process or when filtering or heating a solution. The majority of them exhibited limited understanding of the particulate nature of matter and had difficulties to relate the observable macroscopic changes (i.e., the change in volume when mixing alcohol and water) to the invisible molecular events. They had great difficulties in understanding the molecular constitution of matter, the existence of empty space within matter, and that molecules are constantly in motion irrespectively of the state of matter. Students exhibited also perceptual rather than conceptual understanding and tended to describe molecules as undergoing the same changes as visible changes in the substances. They believed that molecules expand, contract, melt, and combine together to give new molecules without realising the changes in the structure and the properties of matter or without being able to distinguish physical from chemical changes.

The prevalence and diversity of the observed conceptions among PST indicates that most of them are not acquainted with the nature and constitution of matter and that the issue is not adequately addressed during primary and secondary education. It also militates against the Piagetian claim for the universality of cognitive developmental constructions. Piaget (1971; 1974) claimed that ‘atomistic’ conceptions are part of a natural developmental sequence, that is, children construct a notion of atomism as a result of everyday experiences with materials and objects in the physical world. The range and nature of PST’s conceptions support rather the suggestions that ‘atomism’ is not universally acquired in the course of the child’s natural development, but is primarily a function of school studies (Novick & Nussbaum, 1978; 1981; Slone & Bokhurst, 1992).

A lot of studies confirmed that learners bring in the classroom conceptions, which differ in deeply systematic ways from those accepted by the scientific community. These conceptions are not, however, addressed by traditional instruction and textbooks and, consequently, constitute a significant obstacle to learning. Learners’ conceptual framework is usually incompatible with that of the teachers and the textbooks and, thus, they are not "tuned up" to derive the intended meaning from instruction which is, in general, dominated by a transmissionist point of view considering knowledge as an entity to be transmitted or received.

The poor progress in the development of correct conceptions after so many years of schooling seems to indicate that school science should put more emphasis on concepts, such as movement and interaction at the molecular level for explaining the dissolution process or evaporation. Concerning the dissolution process, school science should also differentiate between factors which are essential for a substance to dissolve, such as the solvent-solute interaction or affinity with the solvent, and those factors which simply speed up the dissolution process, such as, stirring, heating, or the aggregation state of the solute.

The subjects studied here are not, however, students in school, but PST on a university course. The study provided strong evidence supporting the conclusion that PST’s ideas are more likely to correspond to those of the children they will teach. Any investigation of PST’s conceptions has, therefore, direct bearing on the possible promulgation of misconceptions amongst many generations of students who will be taught by these teachers. There have been, furthermore, many speculations about the possible origins of misconceptions, but the present study provides strong evidence for at least one origin, that is, the primary teachers themselves. Insight into the range, the nature, and the prevalence of their misconceptions regarding the dissolution of a substance (solid or liquid) in water or the effects of filtering or heating the respective solutions are necessarily an important prerequisite for developing methods to overcome them.

Consequently, schools of education need to devote continuous efforts to prepare teachers who are able to help their students learn properly. Prospective teachers should be encouraged, by one way or another, to expose and articulate openly their conceptions about the physical world. Such efforts will make them aware of the elements of their own conceptions and will facilitate the search for teaching interventions conducive to their conceptual development. Prospective teachers should also be equipped with the necessary capabilities of continuously identifying their own students’ conceptions and implementing teaching approaches that promote conceptual understanding among their students.

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